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Fuzzy reactive power optimization in hybrid power systems

Reza Taghavi, Ali Reza Seifi *, Meisam Pourahmadi-Nakhli

Department of Power & Control, Shiraz University, Shiraz, Iran

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ABSTRACT

Reactive power control, which is one of the important issues of power system studies, has encountered some intrinsic changes because of the presence of the hybrid AC/DC systems. The uncertainty in determination of some ill-defined variables and constraints underlines the application of fuzzy set as an uncertainty analysis tool. Herein a fuzzy objective function and some fuzzy constraints have been modeled for the purpose of reactive power optimization then this fuzzy model is dealt with as a linear programming problem to be solved. Contrary to the separate modeling of the conventional AC/DC optimization methods, this study attempts to attain the most optimal solution by the simultaneous employment of the total contributing factors of both AC and DC parts. In this way, the conventional issue of the coordinated control of firing angle and the transformer tap of the DC terminals is resolved, yet the method provides more flexibility to gain the most optimal condition since it uses more control factor for solving the optimization problem. The proposed method is performed on the modified IEEE 14 and 30-bus systems; and it is shown to have less computational burden and further minimized objective function than the conventional method.

1. Introduction

Nowadays, with the increasing growth of the loads in power systems the need for optimal exploitation of the power systems is of particular interest. One of the important tools that remarkably help in reaching this goal is the optimal power flow because it results in loss decline and more efficient performance under different system conditions. Moreover, it is important to notice that sometimes planners have to take some uncertain constraints and functions in power system studies. This matter is a case for application of fuzzy logic as an uncertainty analysis tool in optimization area. Up to now a comprehensive body of literature exists in reactive power optimization of the AC power systems taking different objective functions and considering uncertain prospective on the optimization issue. There are a few papers attending to the optimal reactive power flow in the hybrid AC–DC systems; yet this confined range of studies just employs the conventional control factors associated with the AC side optimization [1–7]. Thukaram and Visaka introduced a methodology for reactive power optimization in AC/DC systems to control the reactive power flow of the AC system via adjusting the conventional control parameters such as voltage of control bus, transformer taps and static VAR compensators (SVC). Then they inspected the DC-part transformer taps to make sure that taps are within the acceptable range; if the desired condition is achieved the optimization process is finished, otherwise the DC part values get re-initialized to run the optimization once more. This trend will be repeated until the optimal solution is gained; yet in this approach the potential control factors of the DC part does not participate in conjunction with the AC-part factors to solve the optimization problem. The new parameters for the DC part are V_{dc}, I_{dc} and the converter-connected transformer taps. However, conventional models explicitly consider the influence of such DC-related factors. This consideration is in terms of modification of the initial values of DC part without any explanation of the basis on which the changes in the initial values are taken. In [8,9] the FACTS devices enter into the hybrid AC–DC system and reactive power control is performed through a linear programming method with the aim at minimizing the energy of voltage deviations. The presence of UPFC adds some new control factors to the conventional control factors; the new factors such as active and reactive powers delivered through the system-connected line and the bus voltage which is connected to the parallel voltage source of the UPFC model (see Fig. 4 in advance). Authors in [8,9] have disregarded the influence of the DC part factors as well as the UPFC-related factors in reactive power optimization; in addition, because of the separate calculations of the AC and DC parts, the conventional methods need more iterations and considerable size of calculations in each iteration to get the final solution. Using a new approach, this study attempts to attain the optimal condition of reactive power flow in a FACTS-equipped AC/DC system. Herein contrary to the existing methods that attend to the optimization problem with the separate look at the AC and DC

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* Corresponding author.
E-mail addresses: rezataghavi63@gmail.com (R. Taghavi), seifi@shirazu.ac.ir (A.R. Seifi), meisam.pourahmadi@gmail.com (M. Pourahmadi-Nakhli).

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parts, all contributing factors of both AC and DC parts have been used to be simultaneously adjusted for the optimal reactive power flow. The proposed method takes the minimum power loss of the total system as the objective function and directly applies all contributing factors of both AC and DC parts to minimize the loss. In fact a new reactive power optimization modeling is developed, in which model the contribution of all DC and AC control factors is simultaneously brought into optimization. In this way the modification of initial values of the DC part is no longer a critical issue because the effective role of such re-initialization is performed by the new DC control parameters. Also, thanks to the AC–DC-unified optimizing model the conventional issue of coordinated control of the firing angle and converter tap is systematically resolved. On the other hand, it is nearly impossible to precisely determine the states, parameters and constraints of a practical system. Fuzzy systems have been recognized as a powerful discipline for analyzing the problems which have uncertain information on different aspects of parameters, variables, and decisions. In power system studies, especially in load flow analysis, the variables face a wide range of uncertainty resources to be finally determined [10–13]. This forms the basis for employing the fuzzy set as an uncertainty analysis tool for optimization management in such uncertain condition. It is likely to have more optimal solution by employing the fuzzy set in optimization problem because it lets the constraints marginally vary around their limits. Thus, a fuzzy-aided methodology has been applied to two modified 14 and 30-bus systems and the results have been compared with the results of the conventional linear optimization method and proposed AC–DC-unified (but not fuzzy) optimization method. Also, it is shown that the proposed fuzzy method has the advantage of further minimization in objective function in comparison with the conventional method and proposed AC–DC-unified (but not fuzzy) method.

2. Approach

The major contribution that highlights this work in comparison with the conventional methods is that contrary to the existing methods that simplify the whole AC/DC optimization to an AC optimization model jointed with a DC part re-initialization approach, this study takes both AC and DC parts into account and simultaneously models both AC and DC part optimizations into a united model. On this basis, taps and variables of DC part including V_{dc}, I_{dc} and P_{dc} are introduced as new control factors; moreover, the converter's firing angle comes up as a new dependent variable in the calculation of objective function and sensitivity matrix.

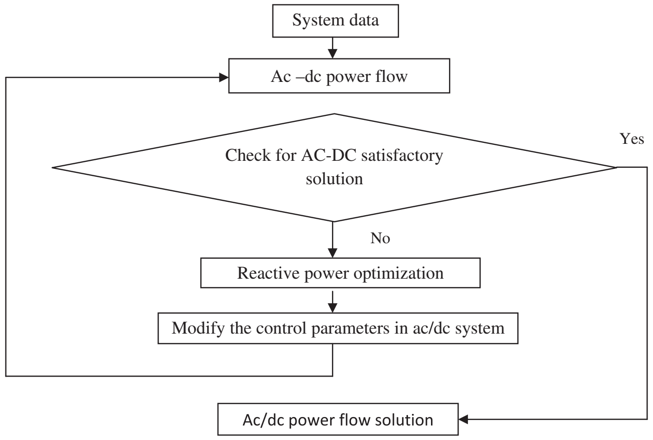

Fig. 1. Flow chart for the reactive power optimization in AC/DC system with UPFC.

The different stages of the optimization are presented in Fig. 1. In block 1 the system data including the control and dependent variables of both parts, control strategies of the DC part – constant voltage control, constant current control, and constant power control strategies – and other necessary data are received. In block 2 the AC/DC power flow is run in presence of UPFC. The total power of DC terminals is modeled in terms of AC loads at buses to which the DC part is connected. In block 3 the system solution is checked to ensure a satisfactory condition. If the success is achieved, the optimization process is finished (block 6), otherwise the reactive power optimization is run using the fuzzy method to yield the range of control parameter changes (block4). In block 5 the control variables get updated by the deviation values which are calculated based on the fuzzy optimization (block 4) and these new inputs are fed back to stage 2. This algorithm is repeated until the optimal condition is gained. It deserves to mention that in each iteration the deviation of control variables should not outrage their constraints so that both control variables and dependent variables become feasible. For example, the DC taps change between their limits so that the firing angles of the converters remain within their allowed limits and in this way the issue of coordinated control of them, which used to be critical in conventional methods, is eliminated. Furthermore, contrary to the introduced method in [8] which needs the modification of the initial DC schedule values, the new control variables of the DC part are systematically changed by the unified model and this automatically takes the role of the conventional re-initialization to conduct the optimization. However, the presence of more control parameters generates more flexibility in minimization of objective function; nevertheless, this makes some principal changes in development of the Jacobean matrix, sensitivity matrix as well as the objective function.

3. Model description

3.1. Converter model

A simple equivalent circuit of one terminal of the monopolar converter is depicted in Fig. 2. Based on the per-unit system which is treated in [9], the equations for each terminal can be stated by:

$$V^{dc} = aV^{dc}\cos(\alpha) - R_c I^{dc} \tag{1}$$

$$P^{dc} = V^{dc} I^{dc} \tag{2}$$

where R_c, a and α are commutation resistance, transformer tab and firing angle, respectively. By neglecting the loss of the converter and its connected transformer and equating the AC and DC powers, the power factor is as follows:

$$V^{dc} = aV^{ac}\cos(\varphi - \varepsilon) \tag{3}$$

And for reactive power which is flowing from the AC part to the converter side, we have:

$$Q^{dc} = P^{ac}\tan(\varphi - \varepsilon) \tag{4}$$

where φ is the voltage angle of AC bus connected to the converter and ε is the angle of AC current injected into the converter. The relationship between the DC voltage of the rectifier side and the DC voltage of the inverter side is:

$$V^{dc}_{rec} = V^{dc}_{inv} + R_{dc} I^{dc} \tag{5}$$

On this basis, the equation for DC current flowing between the two converters is given by:

$$I^{dc} = \left(a_{rec}V^{ac}_{rec}\cos(\alpha_{rec}) - a_{inv}V^{ac}_{inv}\cos(\alpha_{inv})\right)/R_{dc} \tag{6}$$

In Eq. (6), *rec* and *inv* refer to rectifier and inverter buses, respectively.